SCANNING STYLUS ATOMIC FORCE MICROSOPE WITH CANTILEVER TRACKING AND OPTICAL ACCESS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to scanned-stylus atomic force microscopes and a method of operating a scanned-stylus atomic force microscope, and in particular to large scan optical lever atomic force microscopes.

2. Discussion of the Background

Atomic force microscopes (AFMs) are extremely high resolution surface measuring instruments. The AFM is described in detail in several U.S. Patents including U.S. Pat. Nos. 4,935,634 to Hansma et al, 5,025,658 to Flings et al, and 5,144,833 to Amer et al. The AFM scans a stylus mounted on a flexible spring lever (cantilever) with respect to a sample. The actual motion can be produced by translating either the sample or the stylus and cantilever. This motion can be produced by any scanning mechanism, but is typically produced by a piezoelectric translator. All generic scanning mechanisms will be referred to as scanners.

Surface features on the sample interact with the stylus and cause the cantilever to deflect. By measuring the deflection of the cantilever as a function of position over the surface, a map of the surface can be created. In practice, it is often necessary to minimize the force that the cantilever applies to the surface. For this reason, AFMs are usually run under feedback in the "constant force mode." In this mode, the cantilever deflection is kept constant during imaging by moving either the cantilever or the sample with respect to each other. The sample surface is then mapped out by reading a signal indicating the relative motion of the cantilever or sample needed to keep the cantilever deflection constant. When a feedback system is used to keep the cantilever deflection constant, this deflection (and hence force on the sample surface) can be held at a minimum value.

There are also a variety of AC modes where the cantilever is vibrated and features of the sample are sensed by measuring the amplitude, phase, or frequency of the vibrating cantilever. See for example copending application Ser. No. 07/926,175 entitled An Ultra Low Force Atomic Force Microscope by Elings and Gorley.

The first atomic force microscopes used the principal of electron tunneling to detect minute deflections of the cantilever. More recently, two groups (Meyer and Amer, Appl. Phys. Lett., 53 (24), Dec. 12, 1988 and Alexander et al, Appl. Phys. Lett., 65 (1), 1 Jan. 1989 independently succeeded in using the "optical lever technique" to measure cantilever deflections with subnanometer resolution. The "optical lever" technique works in the following way.

Referring to FIG. **1**, a prior art AFM system is illustrated. An AFM cantilever **14** is made so that it is sufficiently reflective that it can act as at least a partial mirror. A laser beam **17** from a laser **10** is focused onto one side of the AFM cantilever **14** having a stylus **15** mounted thereon. Laser beam **14** passes through or alongside a scanner **12** using lens **11** and the reflected beam **18** is directed to a position sensitive detector **16**, usually a multi-segment photodiode. Cantilever **14** is attached to a mounting substrate **20**, which is attached to scanner **12**, or to an optional mounting element **19**. A cantilever deflection changes the angle of the cantilever with respect to the incoming laser beam **17** and thus moves the reflected laser beam **18** on the position sensitive detector **16** as the cantilever **14** is scanned over the sample **13**.

Prior art scanned-stylus AFMs as shown in FIG. **1** focus a laser spot onto one side of a cantilever and then the scanner moves the cantilever over the sample. Since the cantilevers are typically a few hundred microns long and a few tens of microns wide, the focused laser spot must be only 10–30 microns in diameter so that laser light does not spill around the cantilever and onto the sample. If laser light spills around the cantilever, the AFM's sensitivity and therefore vertical resolution is decreased. Also the position sensing photodiode may be disturbed by optical interference from the sample. This means that if a prior art scanned-stylus AFM scans the cantilever more than 10–30 microns, the cantilever will move out from under a stationary laser beam, and the AFM's performance will deteriorate. There is great interest in scanned-stylus AFMs that can scan in the range of 100 microns, much larger than the range of this prior art AFM.

The majority of AFMs that have been built scan a small sample under a fixed stylus and cantilever. There is, however, great interest in AFMs that scan the stylus over a fixed sample. This method has a number of advantages, including the ability to image samples that are too large to be scanned easily. A number of scanned-stylus AFMs have been built and described in the literature. For example, such instruments have been built by G. Meyer and N.M. Amer, Appl. Phys. Lett., 56, p. 2100 (1990), C. B. Prater et al., J. Vac. Sci. Technol., B9, p. 989 (1991), Hipp et al, Ultramicroscopy 42–44, p. 1498 (1992), Putman et al, presented at the OE/LASE '93 Conference, Jan. 19, 1993, Los Angeles, Calif., Baselt and Baldeschweiler Rev. Sci. Instrum. 64, p. 908 (1993), Clark and Baldeschweiler Rev. Sci. Instrum. 64, p. 904, (1993), and by Digital Instruments, U.S. Pat. No. 5,025,658 (E.g., Stand Alone™ AFM, Large Sample Scanning Probe Microscope) assigned to the assignee of the present application.

All of the previous instruments suffer from compromises that do not allow them to take full advantage of the capabilities of AFMs that scan by moving the samples instead of the stylus. Prior art scanned-stylus AFMs that use a fixed laser to measure cantilever deflection have a maximum scan size set by the diameter of the laser beam at the cantilever. If the cantilever is scanned a distance larger than the beam size, it will move out from under the beam, and it will no longer be possible to detect the cantilever motion.

A small number of optical lever scanned-stylus microscopes have been built by using a laser beam that is defocused so that in the plane of the cantilever, it is larger than the desired scan range of the cantilever. Microscopes of this type have been built separately by Meyer et al, supra, C. B. Prater et al. supra, Hipp et al, supra, Baselt et all supra, and Clark et al, supra and are typically of the type shown in FIG. **1**. The performance of this type of scanned-stylus AFM is greatly diminished at scan ranges of larger than 10–20 microns. This performance loss is seen in the form of images that appear "warped" and uncontrolled force variation across the scan field. These effects have been recently described by Baselt et al, supra.

The reason for this performance loss is as follows. Scanned-stylus AFMs often use a piezoelectric tube translator (**12** in FIG. **1**) to scan the cantilever over the sample. Typically, one end of the scanner is held fixed and the other end performs the scanning pattern with a pendulum-like motion. This means that scanning the cantilever over the sample surface changes both the angle and position of the cantilever with respect to the incoming laser beam and the